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(71) Applicant: NORTHROP GRUMMAN CORPORATION [US/US]; 90/110/CC, 1840 Century Park East, Los Angeles, CA 90067-2199 (US).

(72) Inventors: HAMILTON, Robin, E.; 8316 Sunnyview Drive, Millersville, MD 21108 (US). KENNEDY, Paul, G.; 45 Prospect Bay Drive, Grasonville, MD 21638 (US).

(74) Agent: BIRCH, STEWART, KOLASCH & BIRCH, LLP; P.O. Box 747, Falls Church, VA 22040-0747 (US).

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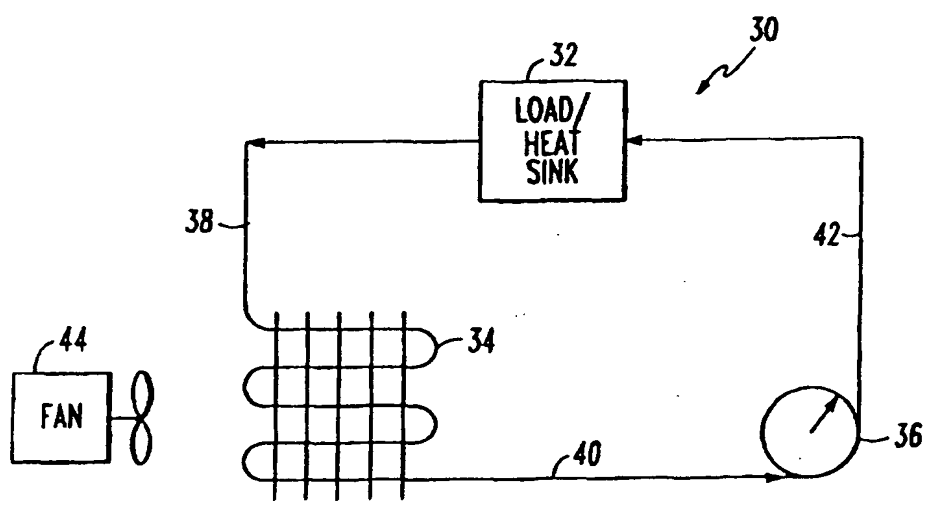

(57) Abstract

A self-contained coolant loop for semiconductor devices such as high power transistors. The coolant loop includes a microchannel heat sink (32), a micropump (36), and an air-to-liquid heat exchanger (34) incorporated into a replaceable module (30).

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CLOSED LOOP LIQUID COOLING WITHIN RF MODULES

Cross Reference to Related Application

This application is related to copending U.S. application Serial No. 08/681,345 (WE58,812) entitled, "Non-Mechanical Magnetic Pump For Liquid Cooling", Robin E. Hamilton et al, filed on July 22, 1996; and

U.S. patent application Serial No. 08/681,207 (WE58,813) entitled, "Microchannel Cooling Of High Power Semiconductor Devices", Robin Hamilton et al, filed on July 22, 1996.

Both of these application are assigned to the assignee of the present invention and are meant to be incorporated herein by reference.

Background of the Invention

Field of the Invention

The present invention relates to convection cooling of high power semiconductor devices and more particularly to a module including a self-contained coolant loop having a microchannel heat sink for cooling relatively high power semiconductive devices, such as RF power transistors.

Description of the Prior Art

State of the art electronic packaging frequently utilizes redundant components in order to compensate for the limited capacity of the means utilized for

cooling. This results in greater system cost, size and weight. For example, in a well known air cooled solid state transmitter such as the ARSR-4 developed by the Westinghouse Electric Corporation, RF power transistors are designed to operate below their power output capability and are spaced relatively far apart from one another in order to meet prescribed operating standards.

The number of transistors and related peripheral circuits that are required in such a solid state transmitter is a function of the thermal capacitance of the transistor device packaging and their associated air cooled heat sinks. The packaging approach utilized by the ARSR-4 solid state transmitter has been embraced by the industry for several years due to its simplicity, low cost and customer acceptance.

Figure 1 is illustrative of an air cooled RF module 10 for an ARSR-4 transmitter. The module 10 is shown including a heat generating transistor chip 12; a ceramic substrate 14; a metallic mounting flange 16; a multilayer soft aluminum clad substrate 18; a metallic ground plane 20; and a cold plate 22 which is a bonded sandwich of aluminum finstock 24 and sheet metal 26. A flow of cooling air directed to the finstock 24 is shown by reference numeral 28.

In accordance with prior art practice, the flange 16 is mounted on the ground plane 20 where it is bolted to the substrate 18. The groundplane 20 is in turn bolted to the air cooled coldplate 22. Advancement in high power device designs, however, has pushed the requirement for efficient thermal designs beyond conventional packaging schemes.

With respect to cooling the structure shown in Figure 1, the maximum device junction temperature of

the transistor devices, not shown, located on the chip 12, as dictated by system reliability studies, is typically between 125 and 135°C. A conventional packaging and realizable air flow delivery limit the maximum heat dissipation of a silicon RF transistor packet such as shown in Figure 1, to about 10 watts. Four design features typically drive the temperature gradient occurring in such a structure. These are the mass of air flow 28, the efficiency of the coldplate 22, the device to substrate interface, i.e. elements 16, 18 and 20, and the internal temperature rise of the chip 12.

Increasing the mass flow rate of air to save in air temperature rise through the electronics is often an almost impossible task. For example, an ARSR-4 transmitter generates over 12 kilowatts average heat dissipation. A blower, not shown, used to cool this very large system is a 20 HP piece of apparatus rated to deliver approximately 10,000 cubic feet per minute of air at 8 inches of water pressure drop. Such a blower is excessively large, expensive and noisy. In fact, such a blower typically requires that it to be housed in its own cabinet.

Alternatively, dramatic improvement in a finstock type air-cooled coldplate 22, without further pushing air flow and pressure drop, is at this time unrealizable. However, the thermal interface between the flange 16, the substrate 18 and the ground plane 20 may be improved with solder. Unfortunately, this adds considerable system cost in module rework. Furthermore, great thermal or electrical efficiency improvements in the device has up to the present eluded transistor vendors.

Although it is known that heat dissipating components may be successfully cooled with liquid,

many end-users have strong objections to liquid cooling because it is perceived to be expensive and heavy, with low reliability and excessive maintenance problems due to leaks, fouling and corrosion. The Federal Aviation Administration (FAA), for example, require that their ground-based radars be cooled with air. Furthermore, many applications simply do not have liquid cooling available.

Summary

Accordingly, it is a primary object of the invention to provide an improvement in the extraction of heat from electronic components.

It is another object of the invention to provide an improvement in the cooling of high power semiconductor devices.

It is yet another object of the invention to provide an improvement in the cooling of densely packaged semiconductor devices by convection cooling.

It is a further object of the invention to provide an improvement in the cooling of high power RF semiconductor devices, such as bipolar transistors, which are utilized in densely packaged configurations.

Briefly, the foregoing and other objects are fulfilled by providing a closed loop liquid cooling arrangement in conjunction with an air-to-liquid heat exchanger integrated into a module which is easily installed and removed as a self-contained unit and furthermore includes a microchannel heat sink which is directly integrated into the chip containing the heat-generating components. Fluid coolant is forced through a plurality of microchannels formed in the heat sink by a micropump located on a substrate formed on a ground plane/heat exchanger which includes coolant input and output ducts coupled to the microchannels. The ground plane/heat exchanger

additionally includes a set of heat exchanger fins which receive air flow from an external blower or fan.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

Brief Description of the Drawings

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein:

Figure 1 is an exploded parts diagram depicting a semiconductor component cooling system according to the known prior art;

Figure 2 is a mechanical schematic diagram broadly illustrative of a modular liquid cooling system in accordance with the present invention;

Figure 3 an exploded parts diagram illustrative of the preferred embodiment of the invention; and

Figure 4 is a perspective view of the unit shown in Figure 3 mounted on the ground plane and including a microchannel heat sink utilized for convection cooling of a plurality of semiconductor devices mounted thereon.

Detailed Description of the Preferred Embodiment

Referring now to the figures and more particularly to Figure 2, shown thereat is a schematic broadly illustrative of the inventive concept of this

invention. In Figure 2, reference numeral 30 denotes a module 30 which includes a load/heat sink 32, a heat exchanger 34 and a fluid coolant pump 36. These elements are shown interconnected by coolant fluid flow paths 38, 40 and 42. In addition, a fan 44 is depicted for forcing air past the heat exchanger 34.

In accordance with the preferred embodiment of the invention, the load/heat sink 32, as shown in Figures 3 and 4, is comprised of a body of material having high thermal conductivity which is attached to a ceramic substrate 48. The ceramic substrate 48 is in turn attached to a metal flange member 50. The flange 50, as shown in Figure 4, includes a pair of open-ended U-shaped slots 52 which are used for being bolted to the soft substrate portion 35 of a circuit board or groundplane member 54 which doubles as an air-to-liquid heat exchanger. As in Figure 1, the groundplane 54 also has a set of heat exchanger fins 56 depending from the bottom portion thereof; however, now the groundplane 54 also includes fluid flow paths or conduits 40 and 42 leading to and from a liquid coolant feed pump 36 located on the soft substrate 35. The ceramic substrate 48 seals the microchannels 62 and serves as a mechanical fluid manifold together with the metal flange 50 and serves to supply a liquid coolant 63 from the pump 36 in and out of the microchannel grooves 62 via pairs of openings 47, 49, and 50, 53. O-ring seals 55 and 57 seal coolant being delivered from and to the pump 36 via the fluid flow paths 40 and 42. A coolant 63, such as FC-43 "Fluorinert" brand liquid manufactured by the 3M Company, comprises an optimum type of coolant liquid because of its high boiling point temperature (174°C) and its non-corrosive nature.

The pump 36 typically comprises a microminiature

piezoelectric diaphragm pump such as shown and described in U.S. patent application Serial No. 08/320,614 entitled, "Micro-Miniature Piezoelectric Diaphragm Pump For The Low Pressure Pumping Of Gases", filed in the names of Robert Young et al on October 7, 1994, and which is meant to be incorporated herein by reference. Alternatively, the pump 36 may comprise a non-mechanical magnetic micropump such as shown and described in the above-referenced copending application Serial No. 08/681,345 (WE58,812), entitled "Non-Mechanical Magnetic Pump For Liquid Cooling", filed in the name of Robin E. Hamilton et al. on July 22, 1996.

Further as shown in Figure 4, the body 46 of the heat sink 32 is shown including a semiconductor chip 58 having integrated therewith a plurality of semiconductor devices 60 which may be, for example, high powered RF bipolar transistors. Beneath semiconductor chip 58 and the semiconductor devices 60, is a plurality of mutually parallel close-ended microchannels 62 of rectangular cross section formed in the material from which the heat sink body 46 is formed.

Each microchannel 62 comprises an elongated linear groove ranging in width between 0.001 in. and 0.004 in., a depth ranging between 0.004 in. and 0.01 in., with the spacing therebetween ranging between 0.001 in. and 0.003 in. The rectangular spacing sections 64 separating the microchannels 62 act as fins for conducting heat generated by the semiconductor devices 60 to the coolant 63 which is pumped through the microchannel 62 by the micropump 36.

For maximum effectiveness in cooling, the heat generating semiconductors, e.g. transistors, can be

formed directly on the microchannel heat sink 32. This eliminates the numerous thermal resistances between the heat source and the heat sink. The microchannels 62 can be inexpensively etched, using standard photolithographic processes, in the body of silicon, for example.

The subject inventive concept is not limited to power transistors. Microchannel cooling may be integrated into different electrical components and even with integrated circuits up to wafer scale level of integration. It can also be used with various semiconductors such as silicon, silicon carbide, germanium and gallium arsenide which in turn are bonded to substrates such as, but not constrained to, beryllium oxide and aluminum nitride.

It can be shown that a microchannel heat sink 32, as depicted in Figure 4, is far more efficient than conventional liquid heat sinks, for example, as shown in Figure 1. The fundamental difference between a microchannel heat sink and a conventional heat sink is the dimensions of the channels 62 (Figure 4). The use of very narrow microchannels enhances heat transfers in two ways. First, narrow channels can be closely spaced, providing a large number of fins 64, with a combined surface area much greater than the "foot print" of the heat sink body 46. In addition, the small hydraulic diameters of the narrow passages result in relatively high convection heat transfer coefficients. Since the thermal conductance of a heat sink is proportional to the product of the convective heat transfer coefficient and the surface area, the microchannels 62 provide an increase in the maximum power density for a given operating temperature and thus are ideal for direct cooling of hot components.

Thus what has been shown and described is a self-

contained coolant loop with a microchannel heat sink coupled to a micropump and an air-to-liquid heat exchanger built right into a module which provides the thermal cooling efficiency of a liquid system while offering the simplicity of an air-cooled package. A structure is provided which can cool electronic devices with twice the heat dissipation than previously practical with air-cooled designs. Integration of higher power components into the electronics thus minimizes parts count, and reduces the quantity of peripheral circuits. Less hardware correlates to less complexity, cost, volume and weight. Most importantly, a self-contained coolant loop eliminates end user's basic objections to liquid systems. Furthermore, there is no cabinet level plumbing to fail or fluid couplings to leak when replacing a unit in the field.

The invention being thus disclosed, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications that would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

CLAIMS

1. A modular type closed loop liquid coolant assembly for supporting and dissipating heat generated by at least one electronics device, comprising:

air-to-liquid heat exchanger means;

heat sink means mounted on said heat exchanger means and including at least one heat generating electronics device thereon and a plurality of convection cooling channels; and

a pump fluidly connected to said cooling channels for circulating a fluid coolant through said cooling channels for providing convection cooling of said electronics device.

2. An assembly according to claim 1 wherein said pump comprises a pump assembly mounted on said heat exchanger means.

3. An assembly according to claim 2 wherein said fluid coolant comprises a liquid coolant.

4. An assembly according to claim 3 wherein said heat exchanger means includes a groundplane.

5. An assembly according to claim 4 wherein said pump is fluidly connected to said cooling channels through said groundplane.

6. An assembly according to claim 5 wherein said heat exchanger means additionally includes a set of air cooled heat dissipating elements extending from said groundplane.

7. An assembly according to claim 6 wherein said set of heat dissipating elements comprises a set of air cooled fins.

8. An assembly according to claim 1 wherein said cooling channels comprise microchannels having a width ranging between about 0.001 in. and about 0.004 in., a depth ranging between about 0.004 in. and about 0.01 in., and a spacing therebetween ranging between about 0.001 in. and about 0.005 in.

9. An assembly according to claim 8 wherein said at least one electronics device comprises at least one semiconductor device.

10. An assembly according to claim 9 wherein said at least one semiconductor device comprises a plurality of semiconductor devices.

11. An assembly according to claim 10 wherein said heat sink means comprises a body of material having relatively high thermal conductivity.

12. An assembly according to claim 11 wherein said plurality of semiconductor devices are integrated in a semiconductor chip located on said body.

13. An assembly according to claim 12 wherein and said plurality of semiconductor devices are located adjacent said microchannels.

14. An assembly according to claim 11 and additionally including a mounting flange for mounting said body on said groundplane.

15. An assembly according to claim 14 wherein said mounting flange includes means for coupling said fluid coolant therethrough between said microchannels and said pump.

16. An assembly according to claim 15 and additionally including a ceramic substrate located between said body of said heat sink means and said mounting flange.

17. An assembly according to claim 16 wherein said ceramic substrate includes means for coupling said fluid coolant therethrough between said microchannels and said pump.

18. A closed loop liquid coolant assembly for supporting and dissipating heat generated by semiconductor devices, comprising:

an air-to-liquid heat exchanger;

a heat sink for electronic devices mounted on said heat exchanger means and including at least one semiconductor device thereon and a plurality of convection cooling microchannels, said microchannels having a width ranging between about 0.001 in. and about 0.004 in., a depth ranging between 0.004 in. and about 0.01 in., and a spacing therebetween ranging between about 0.001 in. and about 0.005 in.; and

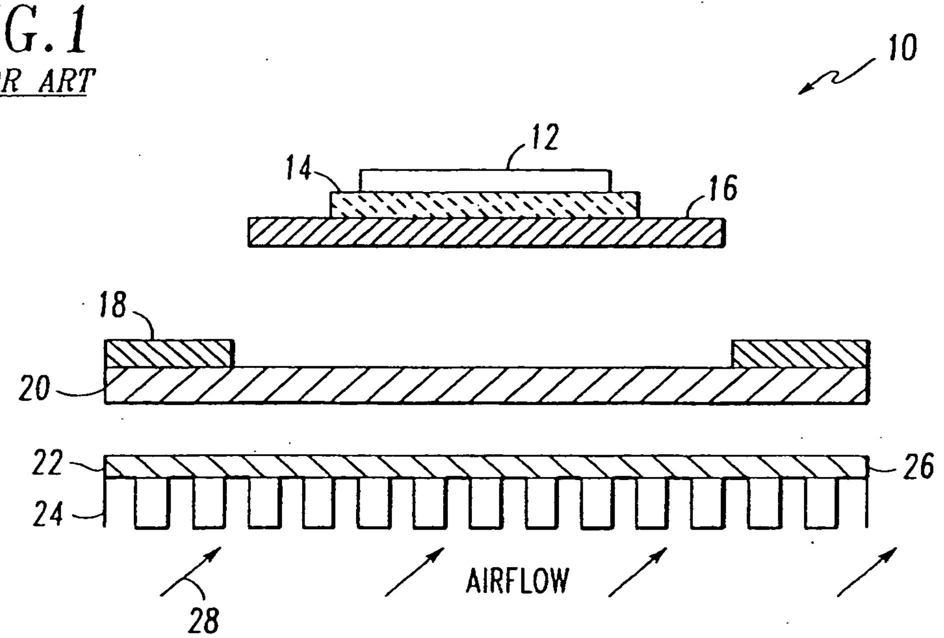
a pump located on said heat exchanger, said heat exchanger including a fluid connection from said pump to said microchannels for circulating a liquid coolant therethrough for providing convection cooling of said

semiconductor device.

19. An assembly according to claim 18 wherein said heat exchanger includes a groundplane for supporting said heat sink and a set of heat dissipating elements for dissipating heat coupled thereto from said liquid coolant flowing in said fluid connection.

20. An assembly according to claim 19 wherein said heat sink includes a semiconductor chip.

FIG.1
PRIOR ART



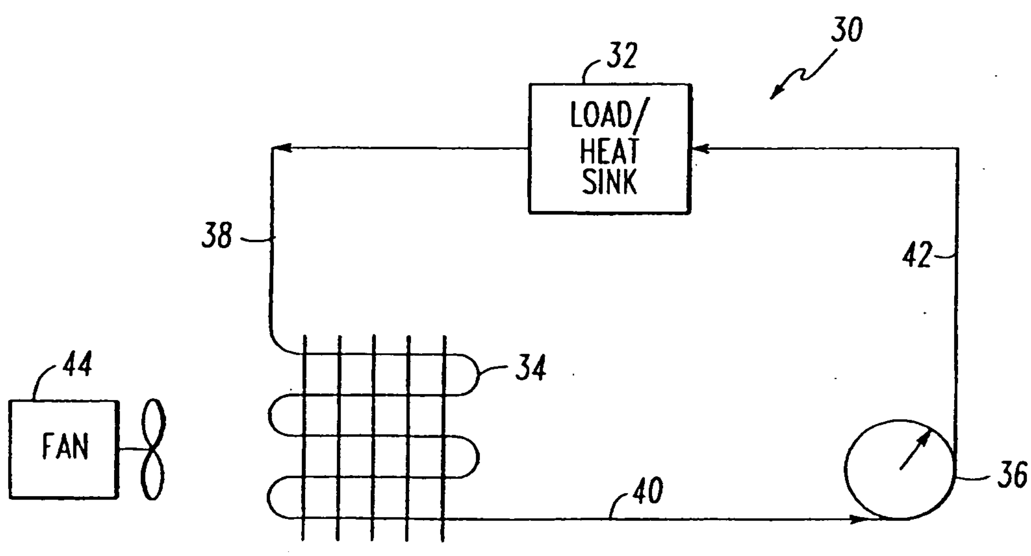
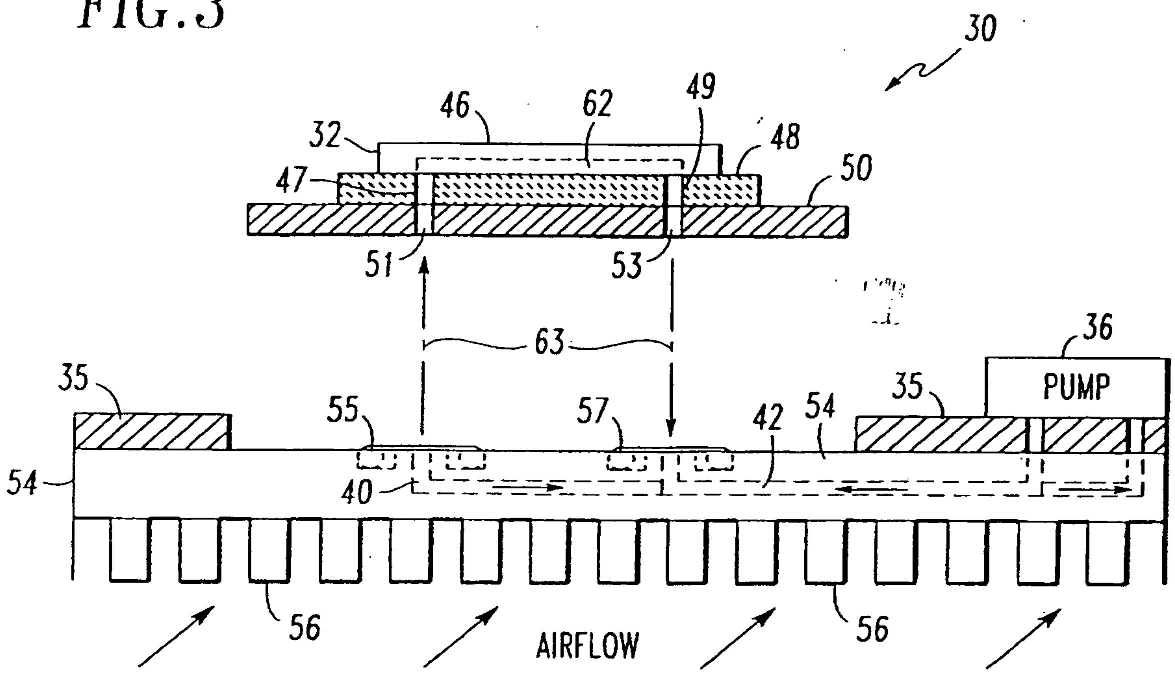


FIG.2

FIG.3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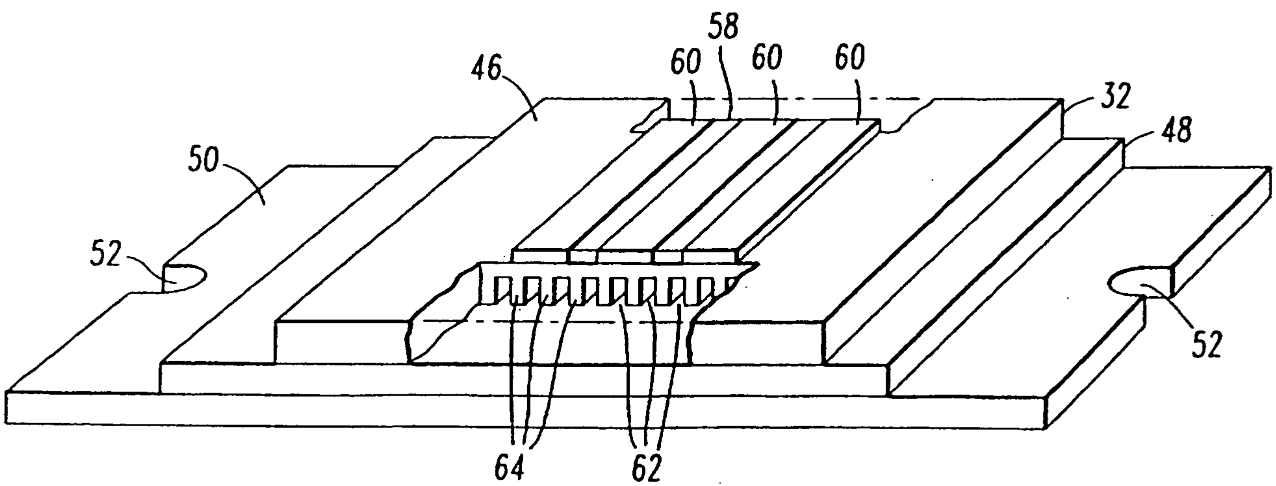
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FIG.4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/13326

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01L23/473

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 316 077 A (REICHARD JEFFREY A) 31 May 1994	1-7
Y	see the whole document	8-13, 18-20
Y	US 4 894 709 A (PHILLIPS RICHARD J ET AL) 16 January 1990 see column 1, line 57 - column 2, line 20; figures 1-3	8-13, 18-20
A	WO 95 08844 A (SIEMENS AG ;KUHNERT REINHOLD (DE); KIFFE WALTER (DE); KNAAK HANS J) 30 March 1995 see the whole document	14-16
X	EP 0 709 885 A (AT & T CORP) 1 May 1996	1-3
A	see the whole document	18

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
10 November 1997	02.12.1997

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Zeisler, P

INTERNATIONAL SEARCH REPORT

Inter onal Application No
PCT/US 97/13326

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	"HERMETICALLY SEALED, FIELD REMOVABLE MODULE HAVING AN INTEGRAL PUMP AND COOLANT HEAT EXCHANGER FOR FORCED CONVECTION IMMERSION COOLING OF ELECTRONIC CIRCUIT MODULES" IBM TECHNICAL DISCLOSURE BULLETIN., vol. 35, no. 4B, September 1992, NEW YORK US, pages 443-444, XP002046249	1-3
A	see the whole document	18

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/13326

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 4894709 A	16-01-90	NONE	
WO 9508844 A	30-03-95	NONE	
EP 0709885 A	01-05-96	AU 3446195 A	09-05-96
		CA 2161823 A	01-05-96
		JP 8213526 A	20-08-96